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U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

3.7.1 SEISMIC DESIGN PARAMETERS

REVIEW RESPONSIBILITIES

Primary - Structural and Geosciences Branch (ESGB)

Secondary - None

I. AREAS OF REVIEW

The following areas relating to seismic design parameters are reviewed:

1. Design Ground Motion

For the seismic design of nuclear power plants, it is customary to specify the earthquake ground motion that is exerted on the structure or on the soil-structure interacting system. The design ground motion, sometimes known as the seismic input or control motion, is based on the seismicity and geologic conditions at the site and expressed in such a manner that it can be applied to the dynamic analysis of structures. The three components of the design ground motions for the operating basis earthquake (OBE) and safe shutdown earthquake (SSE) are reviewed. They should be consistent with the description of the free-field ground motion at the site provided in SRP Section 2.5.2, which includes the variation in and distribution of ground motion in the free field, sources and directions of motion, propagation and transmission of seismic waves, and other site response characteristics.

The control motion should be defined to be on a free ground surface and should be based on data obtained in the free field (Ref. 1). Two cases are identified depending on the soil characteristics at the site and subject to availability of appropriate recorded ground-motion data. When data are available, for example, for relatively uniform sites of soil or rock with smooth variation of properties with depth, the control point (location at which the control motion is applied) should be specified on the soil surface at the top of the finished grade. The free-field ground motion or control motion should be consistent with the properties of the soil profile. For sites composed of one or more thin soil layers overlying a competent material or in case of insufficient recorded ground-motion data, the control point is specified on an outcrop or a hypothetical outcrop at a location on the the top of the competent material. The control motion specified should be consistent with the properties of the competent material. (Note: This information is reviewed under the review responsibility of SRP Section 2.5.2.)

a. Design Response Spectra

Design response spectra are used in the design of seismic Category I structures, systems, and components, and they are generally specified in the free field. The proposed design response spectra for the operating basis earthquake (OBE) and safe shutdown earthquake (SSE) (Ref. 2) are reviewed against the free-field response spectra that are reviewed and accepted under SRP Section 2.5.2. The distinction between the free-field response spectra (site specific or otherwise) reviewed in Section 2.5.2 and the design response spectra reviewed in this section is that a design response spectrum, in general, is a relatively smooth plot not exhibiting random peaks and valleys while a free-field response spectrum may exhibit random sharp peaks and valleys. The use of smooth spectra is preferred in the design and in certain situations it is needed (for example, in the design of a standard plant). The use of unsmoothed response spectra will be reviewed on a case-by-case basis.

b. Design Time History

For computing the response of Category I structures and equipments, acceleration time histories may be used. These time histories must be compatible with the design response spectra, site specific or otherwise, as described above.

When an appropriate recorded or specified time history is not available as input motion for seismic system analysis, an artificial time history (three components) may be generated from the design response spectra for the purpose of carrying out a time history analysis. The response spectra obtained from such an artificial time history of motion should generally envelop the design response spectra for all damping values to be used. The procedures used to generate response spectra are reviewed.

In addition to the comparison of the response spectra derived from the time history with the design response spectra, the frequency intervals at which the spectral values are calculated are also reviewed.

When time history analyses are performed, either of the following options may be considered. In either case the time histories may be real or artificial.

Option 1: Single Time History

Use of single time history is justified by satisfying a target power spectral density (PSD) requirement in addition to the design response spectra enveloping requirements.

Option 2: Multiple Time Histories

In lieu of the use of a single time history, multiple artificial or real time histories may be used for analyses and design of structures, systems, and components. The number and adequacy of time histories with respect to design response spectra are reviewed.

In some instances, a nonlinear analysis of the structures, systems, and components may be appropriate (e.g., the evaluation of existing structures). Multiple time history analyses incorporating real earthquake time histories are appropriate when such analyses are proposed. The adequacy of time histories used in the analyses is reviewed.

2. Percentage of Critical Damping Values

The percentage of critical damping values used for Category I structures, systems, and components is reviewed for both the OBE and the SSE. Critical damping is the amount of damping that would completely eliminate free vibration and is an important measure of the damping capacity of a structure.

Vibrating structures have energy losses that depend on numerous factors, such as material characteristics, stress levels, and geometric configuration. This dissipation of energy, or damping effect, occurs because a part of the excitation input is transformed into heat, sound waves, and other energy forms. The response of a system to dynamic loads is a function of the amount and type of damping existing in the system. A knowledge of appropriate values to represent this characteristic is essential for obtaining realistic results in dynamic analysis.

In practical seismic analysis, which usually employs linear methods of analysis, damping is also used to account for many nonlinear effects such as changes in boundary conditions, joint slippage, concrete cracking, gaps, and other effects that tend to alter response amplitude. In real structures, it is often impossible to separate "true" material damping from system damping, which is the measure of the energy dissipation, from the nonlinear effects. Overall structural damping used in design is normally determined by observing experimentally the total response of the structure.

Only the overall damping used for Category I structures, systems, and components is reviewed. When applicable, the basis for any damping values that differ from those given in Regulatory Guide 1.61 (Ref. 3) is reviewed.

3. Supporting Media for Category I Structures

The description of the supporting media for each Category I structure is reviewed, including foundation embedment depth, depth of soil over bedrock, soil layering characteristics, design groundwater elevation, dimensions of the structural foundation, total structural height, and soil properties to permit evaluation of the applicability of finite-element or lumped-spring approaches for soil-structure interaction analysis.

4. Interface of Review

Review of geological and seismological information to establish the free-field ground motion is performed as described in SRP Sections 2.5.1 through 2.5.3. The geotechnical parameters and methods employed in the analysis of free-field soil media and soil properties are reviewed as described in SRP Section 2.5.4. The results of the reviews for the operating basis earthquake (OBE) and the safe shutdown earthquake (SSE) site-dependent free-field ground motion, soil properties, etc., are used as an integral part of the seismic analysis review of Category I structures.

For those areas of review identified above as being part of other SRP sections, the acceptance criteria necessary for the review and their methods of application are contained in the referenced SRP sections.

II. ACCEPTANCE CRITERIA

The staff accepts the design of structures that are important to safety and that must withstand the effects of the earthquakes if the relevant requirements of General Design Criterion (GDC) 2 (Ref. 4) and Appendix A to 10 CFR Part 100 (Ref. 2) concerning natural phenomena are complied with. The relevant requirements of GDC 2 and Appendix A to 10 CFR Part 100 are:

1. For GDC 2 - The design basis shall reflect appropriate consideration of the most severe earthquakes that have been historically reported for the site and surrounding area with sufficient margin for the limited accuracy, quantity, and period of time in which historical data have been accumulated.

2. For Appendix A to 10 CFR Part 100 - Two earthquake levels, the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE), shall be considered in the design of the safety-related structures, components, and systems.

Specific criteria necessary to meet the relevant requirements of GDC 2 and Appendix A to 10 CFR Part 100 are described below.

The acceptance criteria for the areas of review described in subsection I above are as follows.

1. Design Ground Motion

   a. Design Response Spectra

   The proposed OBE and SSE design response spectra for use in analyses and design of structures, systems, and components should, generally, meet or exceed amplitudes of the site-specific spectra at all frequencies. The use of generic spectra, such as Regulatory Guide 1.60 (Ref. 5) spectra, as design spectra is also acceptable provided that their use is consistent with the information reviewed in SRP Section 2.5.2.

To be acceptable, the design response spectra should be specified for three mutually orthogonal directions--two horizontal and one vertical. Current practice is to assume that the maximum ground accelerations in the two horizontal directions are equal.

b. Design Time History

The SSE and OBE design time histories to be used in the free field of the soil media shall be consistent with those developed or specified in Section 2.5.2. For both horizontal and vertical input motions, either a single time history or multiple time histories can be used.

For linear structural analyses, using site-independent response spectra (e.g., Regulatory Guide 1.60), the total duration of the artificial accelerogram should be long enough such that adequate representation of the Fourier components at low frequency is included in the time history. The total time duration between 10 seconds and 25 seconds is required to adequately match the design response spectra at 0.4 Hz. The corresponding stationary phase strong-motion duration should be between 6 seconds and 15 seconds. If site-specific information reviewed in SRP Section 2.5.2 indicates duration estimates outside the above ranges, the site-specific values should be used. The rationale for selecting lower and upper limits on duration is presented in Reference 6. For nonlinear problems, duration estimates are reviewed on a case-by-case basis.

Option 1: Single Time History

To be considered acceptable, the response spectra of the artificial time history to be used in the free field must envelop the free-field design response spectra for all damping values actually used in the response analysis.

When spectral values are calculated from the artificial time history, the frequency intervals at which spectral values are determined are to be small enough such that any reduction in these intervals does not result in more than 10 percent change in the computed spectra.

Table 3.7.1-1 provides an acceptable set of frequencies at which the response spectra may be calculated. Another acceptable method is to choose a set of frequencies such that each frequency is within 10 percent of the previous one.

Table 3.7.1-1
Suggested Frequency Intervals for Calculation of Response Spectra

Frequency Range (hertz)	Increment (hertz)
0.2 - 3.0	.10
3.0 - 3.6	.15
3.6 - 5.0	.20
5.0 - 8.0	.25
8.0 - 15.0	.50
15.0 - 18.0	1.0
18.0 - 22.0	2.0
22.0 - 34.0	3.0

Each calculated spectrum of the artificial time history is considered to envelop the design response spectrum when no more than five points fall below, and no more than 10 percent below, the design response spectrum.

Recent studies indicate that numerically generated artificial ground acceleration histories produce power spectral density (PSD) functions having a quite different appearance from one individual function to another, even when all these time histories are generated so as to closely envelop the same design response spectra. For example, the use of the available techniques of generating acceleration histories that satisfy enveloping Regulatory Guide 1.60 (Ref. 5) spectra usually results in PSD functions that fluctuate significantly and randomly as a function of frequency. It is also recognized that the more closely one tries to envelop the specified design response spectra, the more significantly and randomly do the spectral density functions tend to fluctuate and these fluctuations may lead to an unconservative estimate of response of some structures, systems, and components. Therefore, when a single artificial time history is used in the design of seismic Category I structures, systems, and/or components, it must in general satisfy requirements for both enveloping design response spectra as well as adequately matching a target PSD function compatible with the design response spectra (Ref. 7). Therefore, in addition to the response spectra enveloping requirement, the use of a single time history will also be justified by demonstrating sufficient energy at the frequencies of interest through the generation of PSD function, which is greater than a target PSD function throughout the frequency range of significance.

When Regulatory Guide 1.60 spectra are used as design spectra the requirements for a compatible target PSD are contained in Appendix A. Target PSD functions other than those given in Appendix A can be used if justified. For site-specific design response spectra or spectra other than Regulatory Guide 1.60 spectra, a compatible target PSD should be generated. For generation of target PSD in such cases, procedures outlined in Reference 6 can be used. For cases where a time history ensemble is used for generation of site-specific spectra, the same time histories can be used to generate mean plus one standard deviation (or 84th percentile) PSD function as a target PSD function. Procedures used to generate the target PSD will be reviewed on a case-by-case basis. The PSD requirements are included as secondary and minimum requirements to prevent potential deficiency of power over the frequency range of interest. It should be noted that the ground motion is still primarily defined by the design response spectrum. The use of PSD criteria itself can yield time histories that may not envelop the design response spectrum.

Option 2: Multiple Time Histories

As discussed in Section I.1.b of this SRP, the use of multiple real or artificial time histories for analyses and design of structures, systems, and components is acceptable. As a minimum, four time histories should be used for analyses. Any lesser number will be reviewed and accepted on a case-by-case basis.

The parameters describing the time histories and the calculated response spectra for each time history are reviewed. The response spectra calculated for each individual time history need not envelop the design response spectra. However, the multiple time histories are acceptable if the average calculated response spectra generated from these time histories envelop the design response spectra. The design response spectra are considered to be the mean plus one standard deviation (or 84th percentile) response spectra as defined in Section 2.5.2.

The review of the real time histories used in the nonlinear analysis is conducted on a case-by-case basis. Some of the specific items of interest are number of time histories, frequency content, amplitude, energy content, duration, number of strong-motion cycles, and the basis for selection of time histories.

Additional information on the use of multiple time histories can be found in Reference 8. This information may be used for reference only, as it does not constitute the staff's acceptance criteria.

2. Percentage of Critical Damping Values

The specific percentage of critical damping values used in the analyses of Category I structures, systems, and components are considered to be acceptable if they are in accordance with Regulatory Guide 1.61 (Ref. 3). Higher damping values may be used in a dynamic seismic analysis if test data are provided to support them. These values will be reviewed and accepted by the staff on a case-by-case basis.

In addition, a demonstration of the correlation between stress levels and damping values will be required and reviewed for compliance with regulatory position C.3 of Regulatory Guide 1.61. Methods for correlation of damping values with stress level are discussed in References 8 and 9. If such methods are used, they will be reviewed and accepted on a case-by-case basis.

The damping values for foundation soils must be based upon measured values or other pertinent laboratory data, considering variation in soil properties and strains within the soil, and must include an evaluation of dissipation from pore pressure effects as well as material damping for saturated site conditions.

3. Supporting Media for Category I Structures

To be acceptable, the description of supporting media for each Category I structure must include foundation embedment depth, depth of soil over bedrock, soil layering characteristics, design groundwater elevation, dimensions of the structural foundation, total structural height, and soil properties such as shear wave velocity, shear modulus, Poisson's ratios, and density as a function of depth.

III. REVIEW PROCEDURES

For each area of review, the following review procedure is followed. The reviewer will select and emphasize material from the procedures given below as may be appropriate for a particular case. The scope and depth of review procedures must be such that the acceptance criteria described above are met.

1. Design Ground Motion

a. Design Response Spectra

Design response spectra for the OBE and SSE for all damping values are checked to ensure that the spectra are in accordance with the acceptance criteria as given in subsection II. Any differences between the free-field spectra and the proposed design response spectra that have not been adequately justified are identified, and the applicant is informed of the need for additional technical justification.

b. Design Time History

Methods of defining the design time histories are reviewed to confirm that the acceptance criteria of subsection II.2 of this SRP section are met.

2. Percentage of Critical Damping Values

The specific percentage of critical damping values for the OBE and SSE used in the analyses of Category I structures, systems, and components are checked to ensure that the damping values are in accordance with the acceptance criteria as given in subsection II.2 of this SRP section. Any differences in damping values that have not been adequately justified are identified, and the applicant is informed of the need for additional technical justification.

3. Supporting Media for Category I Structures

The description of the supporting media is reviewed to verify that sufficient information, as specified in the acceptance criteria of subsection II.3 of this SRP section, is included. Any deficiency in the required information is identified, and a request for additional information is transmitted to the applicant.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and that his evaluation supports conclusions of the following type, to be included in the staff's safety evaluation report.

The staff concludes that the seismic design parameters used in the plant structure design are acceptable and meet the requirements of General Design Criterion 2 and Appendix A to 10 CFR Part 100. This conclusion is based on the following.

The applicant has met the relevant requirements of GDC 2 and Appendix A to 10 CFR Part 100 by appropriate consideration for the most severe earthquake recorded for the site with an appropriate margin and considerations for two levels of earthquakes--the safe shutdown earthquake (SSE) and operating basis earthquake (OBE). The applicant has met these requirements by the use of the methods and procedures indicated below.

The seismic design response spectra (OBE and SSE) applied in the design of seismic Category I structures, systems, and components meets or exceeds the free-field response spectra provided in Section 2.5.2. The percentage of critical damping values used in the seismic analysis of Category I structures, systems, and components are in conformance with Regulatory Guide 1.61, "Damping Values for Seismic Analysis of Nuclear Power Plants." The artificial time history used for seismic design of Category I plant structures, systems, and components is adjusted in amplitude and frequency content to obtain response spectra that envelop the design response spectra specified for the site and also exhibits sufficient energy in the frequency range of interest. Conformance with the recommendations of Section 2.5.2 and Regulatory Guide 1.61 ensures that the seismic inputs to Category I structures, systems, and components are adequately defined so as to form a conservative basis for the design of such structures, systems, and components to withstand seismic loadings.

V. IMPLEMENTATION

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this SRP section.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

Implementation schedules for conformance to parts of the method discussed herein are contained in the referenced regulatory guides.

The provisions of this SRP section apply to reviews of construction permit (CP), preliminary design approval (PDA), final design approval (FDA), and combined license (CP/OL) applications docketed after the date of issuance of this SRP section. Operating license (OL) and final design approval (FDA) applications, whose CP and PDA reviews were conducted prior to the issuance of this revision to SRP Section 3.7.1, will be reviewed in accordance with the acceptance criteria given in the SRP Section 3.7.1, Revision 1, dated July 1981.

VI. REFERENCES

1. "Proceedings of the Workshop on Soil-Structure Interaction," Bethesda, MD, NUREG/CP-0054, June 16-18, 1986.
2. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."
3. Regulatory Guide 1.61, "Damping Values for Seismic Analysis for Nuclear Power Plants."
4. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."
5. Regulatory Guide 1.60, "Design Response Spectra for Nuclear Power Plants."
6. A. J. Philippacopoulos, "Recommendations for Resolution of Public Comments on USI A-40, Seismic Design Criteria," NUREG/CR-5347, April 1989.
7. M. Shinozuka, T. Mochio, and E. F. Samaras, "Power Spectral Density Functions Compatible with NRC Regulatory Guide 1.60 Response Spectra," NUREG/CR-3509, June 1988.
8. D. W. Coats, "Recommended Revisions to Nuclear Regulatory Commission Seismic Design Criteria," NUREG/CR-1161, May 1980.
9. ASCE Standard 4-86, "Seismic Analysis of Safety-Related Nuclear Structures and Commentary on Standard for Seismic Analysis of Safety-Related Nuclear Structures," American Society of Civil Engineers, September 1986.

APPENDIX A TO SRP SECTION 3.7.1

SPECIFICATION FOR MINIMUM POWER SPECTRAL DENSITY (PSD) REQUIREMENT

For a Regulatory Guide 1.60 horizontal response spectrum anchored to 1.0g, the following minimum PSD requirement should be satisfied. For other peak accelerations, this PSD requirement should be scaled by the square of the peak acceleration.

The one-sided PSD is related to the Fourier amplitude $|F_{(\omega)}|$ of the time history by the equation

$$S_{0(\omega)} = \frac{2\ |\ F_{(\omega)}\ |^2}{2\Pi\ T_D} \quad \text{.................... (1)}$$

where T_D is the strong-motion duration over which $F_{(\omega)}$ is evaluated. This duration T_D represents the duration of near maximum and nearly stationary power of an acceleration time history record. Additional guidance on estimation of T_D for artificial time history or actual earthquake time history is provided in Appendix B of Reference 6.

The averge one-sided PSD defined by Equation (1) should exceed 80 percent of the target PSD as defined by Equation (2) from 0.3 Hz to 24 Hz.

Less than 2.5 Hz

$S_{0(\omega)}$ = 650 inch²/sec³ $(f/2.5)^{0.2}$

2.5 Hz to 9.0 Hz

$S_{0(\omega)}$ = 650 inch²sec³ $(2.5/f)^{1.8}$ .... (2)

9.0 Hz to 16.0 Hz

$S_{0(\omega)}$ = 64.8 inch²/sec³ $(9.0/f)^3$

Greater than 16 Hz

$S_{0(\omega)}$ = 11.5 inch²/sec³ $(16.0/f)^8$

At any frequency f, the average PSD is computed over a frequency band width of ±20 percent centered on the frequency f (e.g., 4 to 6 Hz band width for f=5 Hz).

The power above 24 Hz for the target PSD is so low as to be inconsequential so that checks above 24 Hz are unnecessary. (However, note that the response spectrum calculations are required beyond 24 Hz as governed by Regulatory Guide 1.60 definitions.) Similarly, power below 0.3 Hz has no influence on stiff nuclear plant facilities so that checks below 0.3 Hz are unnecessary. This minimum check is set at 80 percent of the target PSD so as to be sufficiently high to prevent a deficiency of power over any broad frequency band, but sufficiently low that this requirement introduces no additional conservatism over that already embodied in the Regulatory Guide 1.60 response spectrum.

A time history meeting this minimum PSD requirement will produce a response spectrum that lies below the Regulatory Guide 1.60 response spectrum at all frequencies. To produce a response spectrum that accurately fits the 2 percent damped, 1.0g, Regulatory Guide 1.60 response spectrum at all frequencies above 0.25 Hz, the PSD defined by Equation (2) can be used with the resulting time history being clipped at ±1.0g (Ref. 7).

To produce a response spectrum that conservatively envelops the 1.0g Regulatory Guide 1.60 response spectrum at 2 percent damping and greater, a PSD set at 130 percent of the PSD defined by Equation (2) can be used with the resulting time history being clipped at ±1.0g.